

# Need for the Development of Advanced Computational Methods to Determine Smoke Movement in Large Buildings

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## ABSTRACT

A relatively large proportion of deaths in fires result due to the inhalation of combustion products, away from the combustion sites. Generation rate of harmful gases critically depends upon the temperature reached. Hence, accurate prediction of maximum temperature reached, faithful modeling of the generation rate of harmful gases [1], and accurate determination of smoke movement away from the fire source through rooms, corridors, and stairways are essential for accurate fire safety assessment and codes.

Zone models have traditionally been used to characterize smoke movement in enclosed areas. Considerable number of assumptions and simplifications are necessary in the development and analysis of zone models. Though recent developments in computer hardware and numerical methods now permit increasing use of *field models*—which are based on local conservation of mass, momentum, energy and species, expressed in the form of partial differential equations—such applications are still somewhat limited to small computational regions due to the large number of grid points (and hence large computing resources) required by conventional numerical schemes. New computational techniques that will permit the solution of field equations over large volumes—such as those in typical buildings—are hence, very desirable. These methods will allow accurate solution of field equations to determine smoke movement over complex geometry in large buildings, and hence will help in the establishment of accurate fire safety codes.

Development of nodal methods and their applications over the last two decades to various branches of science and engineering has clearly shown that these methods are superior to more conventional numerical techniques, and lead to far more accurate results for given mesh size; or for specified accuracy, need far fewer "grid points" than conventional schemes, such as upwind-difference scheme. These methods have been applied to solve among other problems, the particle transport equation, neutron diffusion equation, Fokker-Planck equation, Navier-Stokes equations, Navier-Stokes-Boussinesq equations, and the convection-diffusion equation. In all cases the results have been exceptionally encouraging.

The main idea behind the nodal integral methods (NIM) is to not blindly subject the entire set of field equations to discretization, but rather to attempt *to solve as much of these equations analytically as possible*. This does require *some* approximations, and a certain amount of one time pre-processing, which pays off handsomely at the numerical calculation stage. Reference 2 outlines a typical application of the nodal integral method to solve the convection-diffusion equation. To show the superiority of the NIM, results obtained for a standard benchmark problem, solved using the NIM and using the upwind-difference scheme, are presented here. The rectangular computational domain,  $-1 \leq x \leq +1$ ,  $0 \leq y \leq 1$ , is shown in Fig. 1. The flow is recirculating, where the velocity field is given analytically as  $u = 2y(1-x^2)$  and  $v = -2x(1-y^2)$ . Constant Dirichlet boundary conditions are specified at the top, and the left and right walls of the domain. A specific temperature profile,  $T(x,y=0) = 1 + \tanh(10(2x+1))$ , is given at the domain flow inlet ( $-1 \leq x \leq 0$ ), and a no-conduction boundary condition is given at the domain flow outlet ( $0 < x \leq 1$ ,  $y = 0$ ). The standard convection-diffusion equation is solved using a convergence criterion of  $10^{-14}$  for both the upwind-difference scheme (UWDS) and the NIM. Table 1 shows that, for  $Pe = 10^3$ , the NIM solution obtained on a  $60 \times 30$  mesh with a percent relative average  $L_1$  error of 0.1406, is more accurate than that obtained by the UWDS on a  $700 \times 350$  mesh which has a corresponding error of 0.7262. NIM, even with five times smaller error, is faster than the UWDS by about 950 times. Clearly, the analytical pre-processing in the development of the NIMs, leads to a scheme that can yield very accurate results on rather coarse

mesh size. This property of the NIM will be very beneficial in solving the smoke movement problem in large size buildings.

Field equations—mass, momentum, energy and species conservation equations—to be solved to determine smoke movement are similar to those to which NIM has already been successfully applied [3]. Hence, no conceptual difficulty is foreseen in developing a NIM for this problem. As far as turbulence is concerned, either a standard  $k-\epsilon$  type turbulence model can be incorporated in the NIM development, or a nodal method can be developed to directly solve the inviscid equations of conservation in the Boussinesq approximation. Though the problem described above is steady-state, extension to time-dependent problems, though non-trivial, is straight forward. Nodal integral methods have already been developed to solve time-dependent problems. A recently developed *modified* nodal integral method when applied to (time-dependent) Burgers equation shows results that are even better than those obtained using conventional nodal integral method [4].

Clearly, the problem of the transport of combustion products from fires, due to rather large computational domain involved, can take advantage of these advanced computational methods, making it possible to solve the smoke generation and movement problem in large size buildings.

## References

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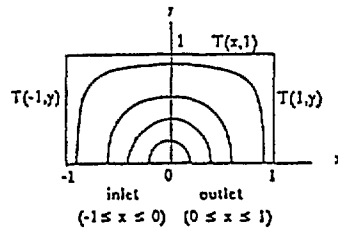


Fig. 1.

Table 1: Percent relative average L-1 errors of NIM vs. UWDs for a recirculating flow problem which has a sudden rise in inlet temperature profile and  $Pe = 10^3$ .

Mesh	% Relative Average L-1 Errors		CPU (sec)	
	UWD*	NIM**	UWD	NIM
20 x 10	1.40061E+01	1.53124E+00	0.06	0.12
60 x 30	6.53091E+00	1.40663E-01	0.45	1.60
100 x 50	4.37948E+00	4.85390E-02	3.27	12.29
140 x 70	3.31469E+00	2.42280E-02	10.10	51.38
180 x 90	2.67006E+00	1.44600E-02	24.91	139.68
220 x 110	2.23504E+00	9.59382E-03	52.54	312.84
260 x 130	1.92061E+00	6.82725E-03	101.86	618.13
300 x 150	1.68223E+00	5.10653E-03	175.65	1100.92
340 x 170	1.49505E+00	3.96427E-03	281.73	1867.65
700 x 350	7.26169E-01	9.35244E-04	1546.98	13695.41